Inner Crystal Calorimeter for EIC (part of eRD1)

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EIC R&D Committee Meeting

Jefferson Lab, July 13-14, 2017

Students

- Dannie Griggs (Marshall High school)
- Abby McShane (Marshall High school)
- Salim Roustom (Marshall High school)
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- Frederic Georges (IPN-Orsay)
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- Andres Vargas (CUA)
- Marco Carmignotto (CUA)
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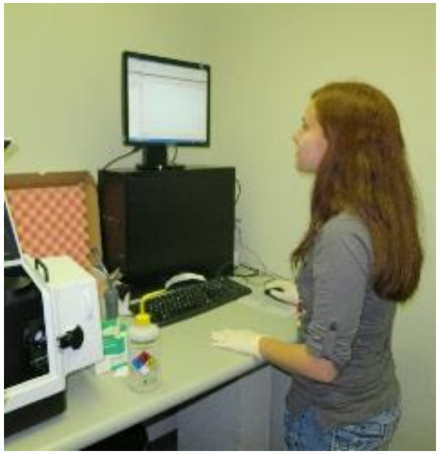
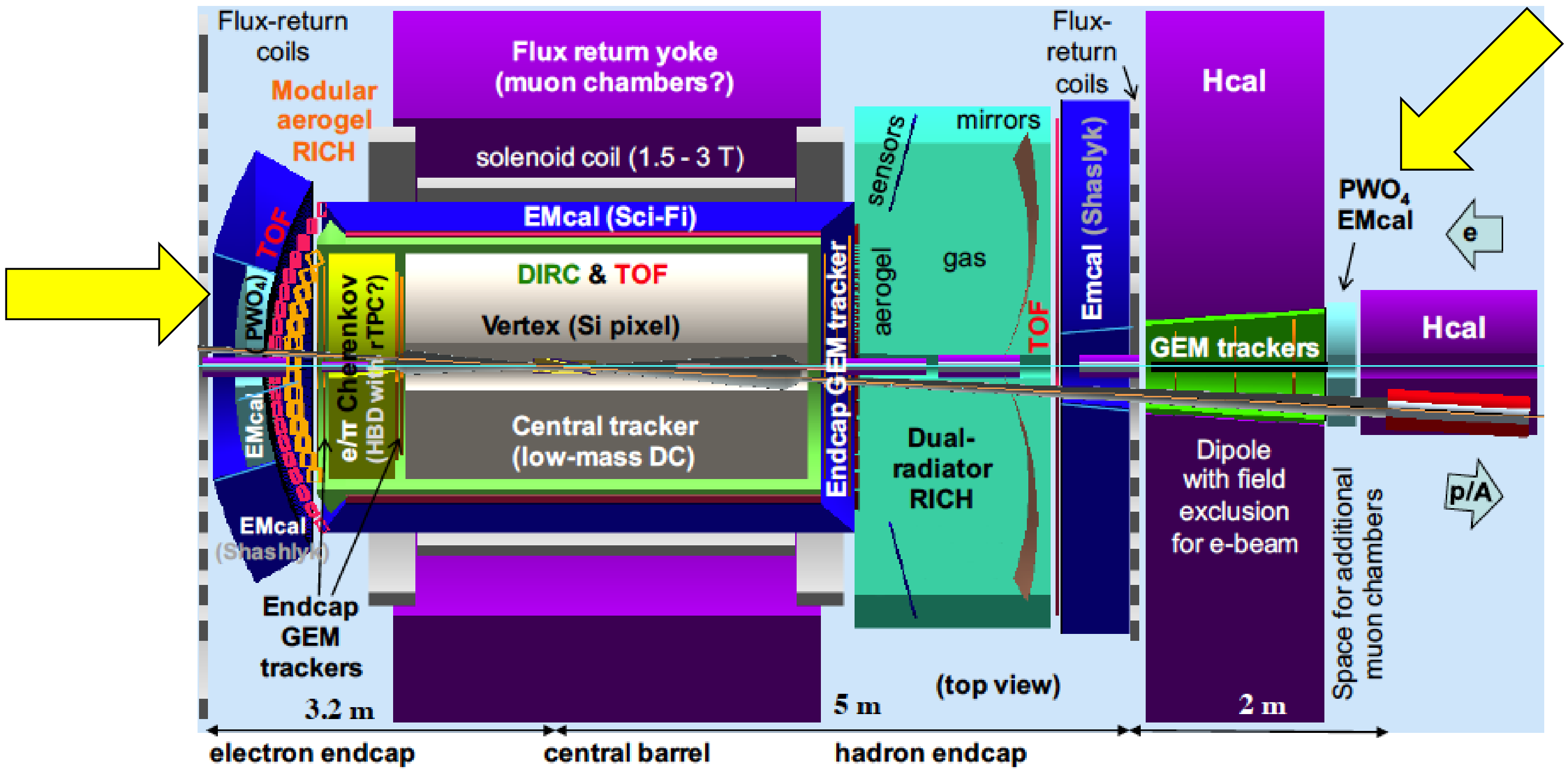


High resolution calorimetry for endcaps

- **PID requirements in the electron endcap** primarily driven by nearly real photo-production and semi-inclusive and exclusive processes
- **PID requirements in the ion endcap** primarily driven by exclusive processes, e.g., DVCS (γ vs. photons from π^0 decay) and to detect excitation in recoil baryons

Detection at very small angle is needed

Example: JLEIC detector



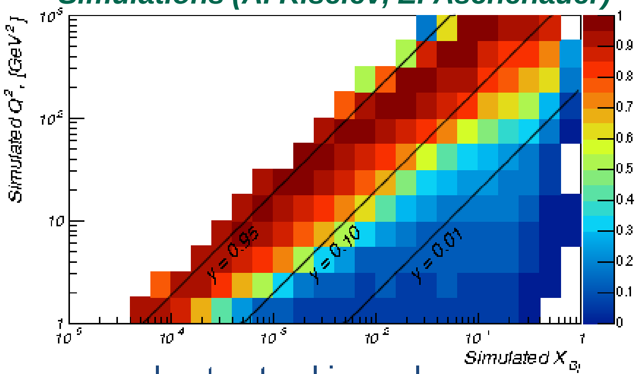
High resolution calorimetry – functions and requirements

❑ EM calorimetry has two main functions

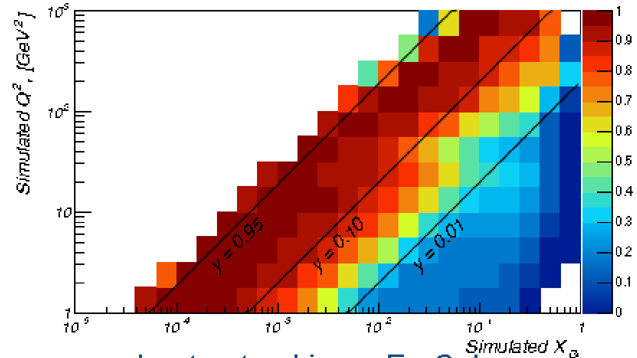
- **Particle Identification**: important for discriminating single photons from, e.g., π^0 decay and *e/p*

- **Particle Reconstruction**: driven by need to accurately reconstruct the four-momentum of scattered electrons at small angles, where the momentum (or energy) resolution from the tracker is poor.

Simulations (A. Kiselev, E. Aschenauer)



Lepton tracking only



Lepton tracking + EmCal

❑ EM Inner Calorimeter Requirements

- Good resolution in angle to *at least 1 degree* to distinguish between clusters

- Energy resolution *(1-1.5%)/√E + 0.5%* for measurements of cluster energy
    - Resolution helps to extend useful y-range, "purity" in x/Q^2 bins

- Time resolution to *< 2ns*

- Ability to withstand radiation down to at least 1 degree wrt beam line

What was planned for FY17

$PbWO_4$ is optimal for the inner crystal calorimeter. R&D is necessary to develop process towards acceptable crystals quality assurance towards EIC needs and to ensure worldwide availability of high quality crystals

Need to develop process towards acceptable crystals quality assurance towards EIC needs.

- Finalize infrastructure for full crystal testing facilities at CUA and IPNO, and understand systematic effects in characterization of 2014+ SICCAS produced crystals

Need to develop an alternate supplier of $PbWO_4$

- *Procure a reasonable batch of full-sized crystals from CRYTUR to evaluate crystal-to-crystal variation and impact of impurities on performance*

Need to cross check system performance of acceptable crystals.

- Construct a prototype to study actual energy and position resolution of SICCAS or CRYTUR crystals with test beam and test different readout systems

What was achieved in FY17

With commitment of internal university and laboratory funds and through synergy with the NPS project at JLab we made progress even within constrained FY17 budgets

Crystal characterization for specifications and impact on EIC detector performance

- ❖ Individual crystal testing infrastructure complete. Work towards testing systematics between setups
- ❖ Results for 2014/15 crystals and setting up to test crystals being produced in 2017 in collaboration with NPS project
- ❖ Crystal chemical analysis methods established and initial results on contribution of impurities, defects and stoichiometry. Work towards developing non-destructive sampling methods

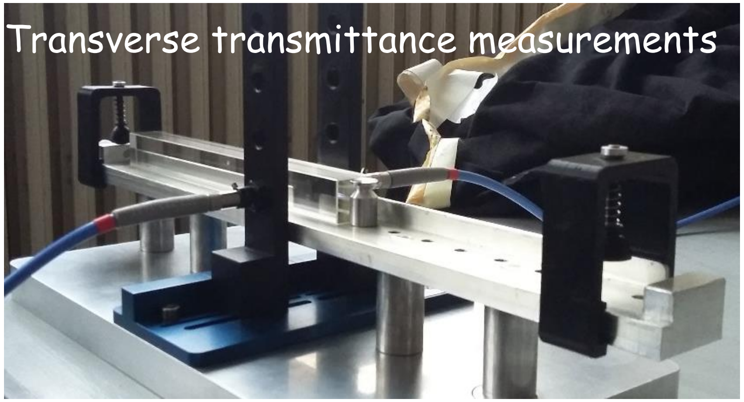
❖ **Prototype construction to establish limiting energy and position resolution and to test readout systems**

- ❖ Work towards construction of a prototype to test different readout options, e.g. PMT, as well as APD and SiPM
- ❖ Results of PbWO4 with SiPM readout from beam test at Fermilab

Infrastructure for crystal testing - *completed*

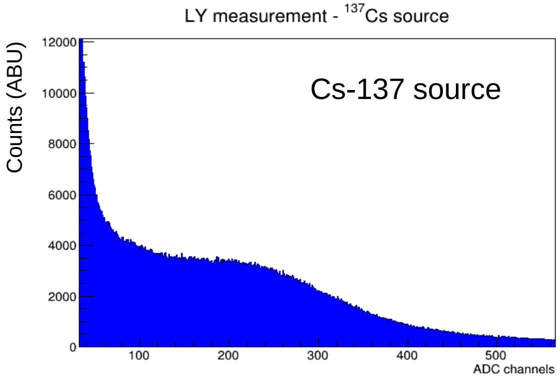
IPN-Orsay (France) – proximity to Giessen U. and CRYTUR

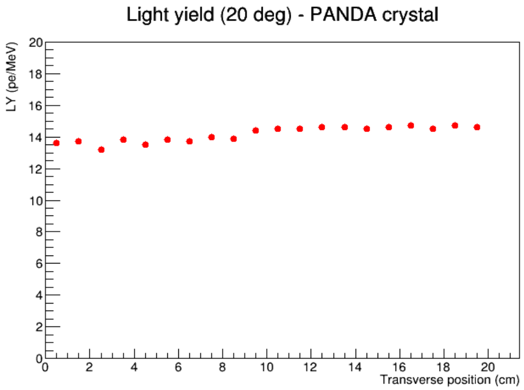
- Optical Transmittance (L/T)
  - Fiber-based spectrometer
- Radiation Hardness
  - Strong ^{60}Co sources available at LCP-Orsay
  - ALTO facility can provide 50 MeV electrons up to 1μA. A Proton beam (Tandem) is also available



Laboratoire de Chimie Physique (Orsay)

- Crystal light yield and timing
  - ***Cross check with subset of crystals previously tested at CUA, Giessen and Caltech ongoing***



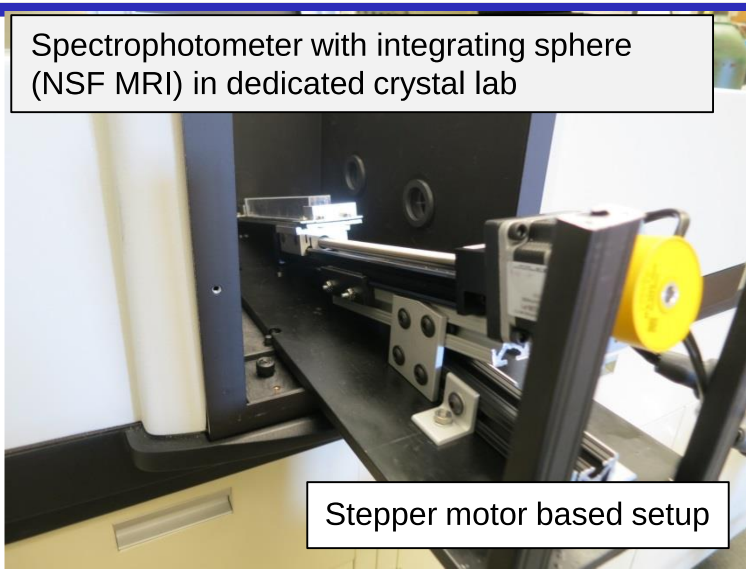


Infrastructure for crystal testing - *completed*

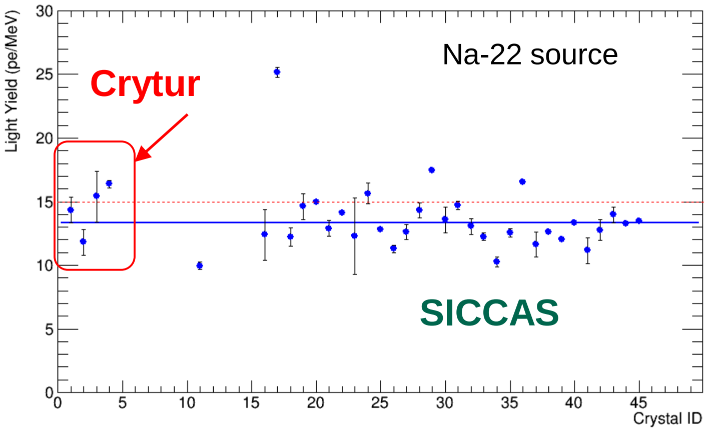
THE CATHOLIC UNIVERSITY of AMERICA

CUA (USA) – proximity to JLab, SICCAS crystals

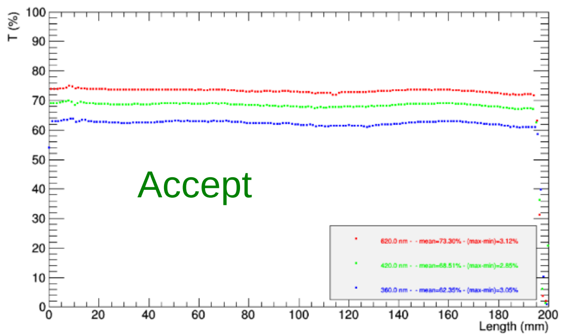
- Optical Transmittance (L/T)
  - Perkin-Elmer Lambda 950 with integrating sphere
- Radiation Hardness
  - X-Ray and Co-60 source
  - ***~50% of SICCAS 2014+ and ~80% of Crytur crystal subset passes requirement at 420nm***
- Crystal light yield and timing
  - ***~50% of SICCAS and ~20% of Crytur crystals pass specs, changes in doping increases LY***

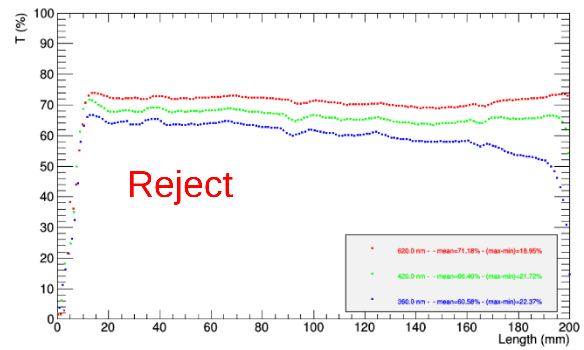


Light Yield for Crytur and SICCAS



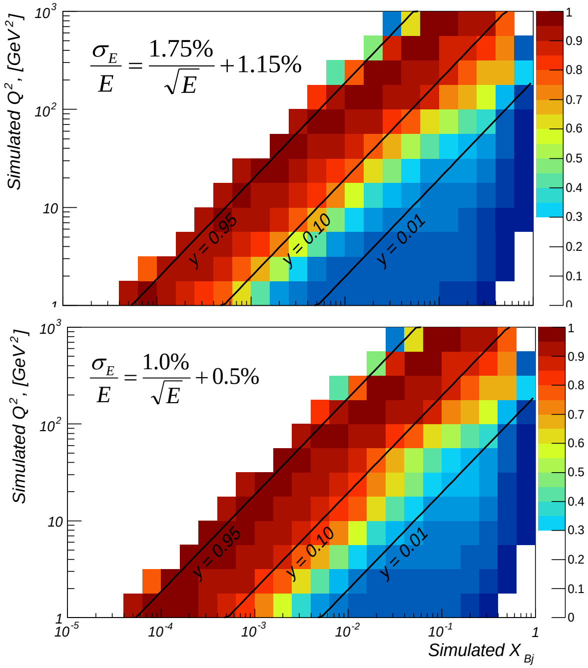
Transverse transmittance crystal-to-crystal variations





Energy Resolution – design parameters

Simulations (A. Kiselev, E. Aschenauer)

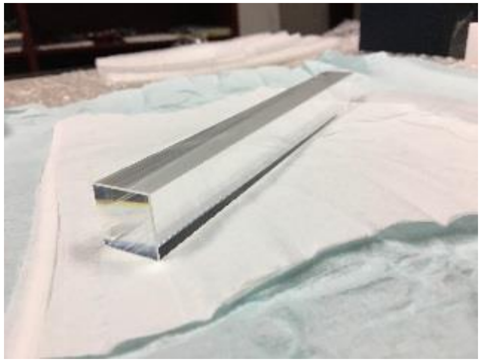


- Limits of energy resolution depend on the energy range of interest – many factors contributing
- Carried out simulations to establish a basic set of parameters. Results suggest that to make a clear positive impact on EIC physics, the crystal calorimeter should have:
  - Stochastic term: 1.0% - 1.5%
  - **Constant term (noise level): ~0.5%**

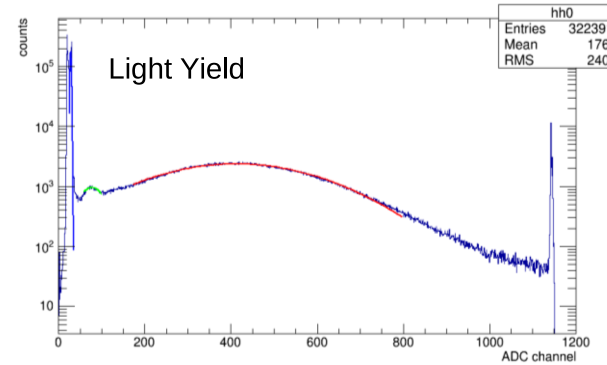
Important factors contributing to noise level we focus on:

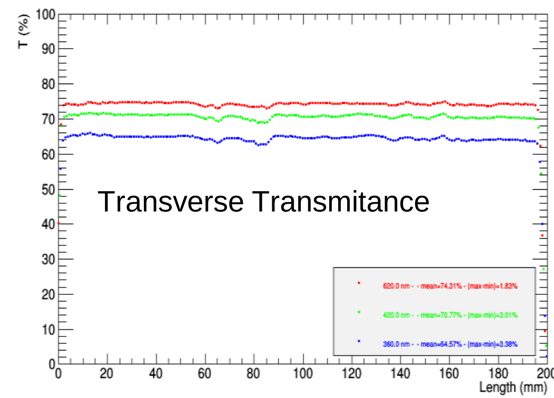
- ***Crystal quality*** and uniformity (LY, dk, etc.) including composition and surface effects - **ongoing**
- ***Choice of readout*** and its contribution to noise level – for ***PMTs*** noise level can be ignored since cutting at 1 p.e. - **ongoing**
- **Next: *prototype to determine ultimate limits of resolution and test readout systems*** - for optimal resolution tests a 5x5 matrix is required

Crystal Quality: Impact of impurities and defects

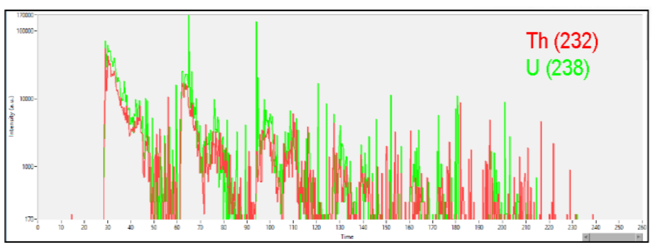


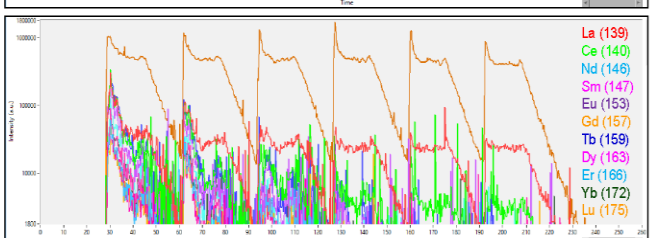
- Completed analysis of a full size Crytur crystal from 5th production cycle (expect more impurities)
  - *Low light yield* (10 pe/MeV at 18°C)
  - Acceptable transmittance and radiation hardness



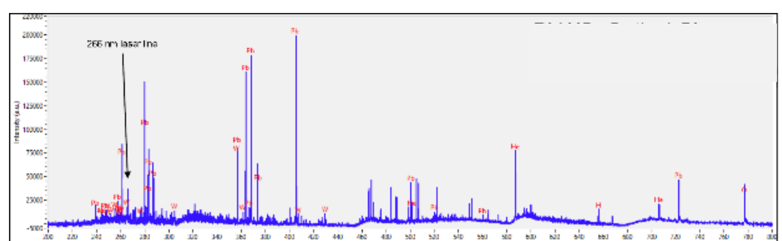


- Chemical analysis ongoing to determine crystal composition
  - X-Ray Fluorescence (XRF) and ICP-MS, developing non-destructive sampling methods
  - One 2014 SICCAS crystal (J01) analyzed – results indicate impurities at the few percent level

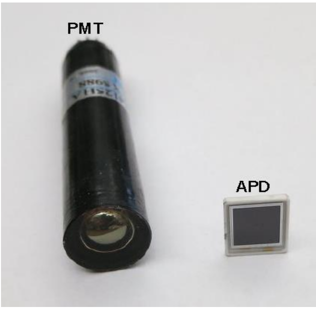


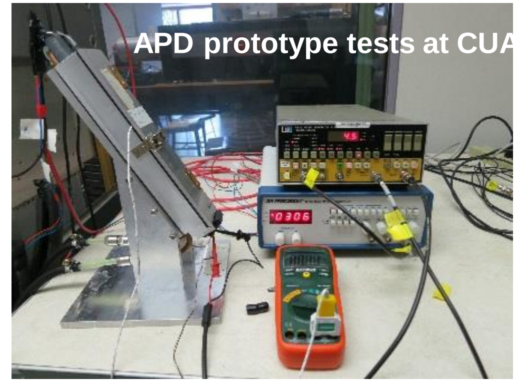


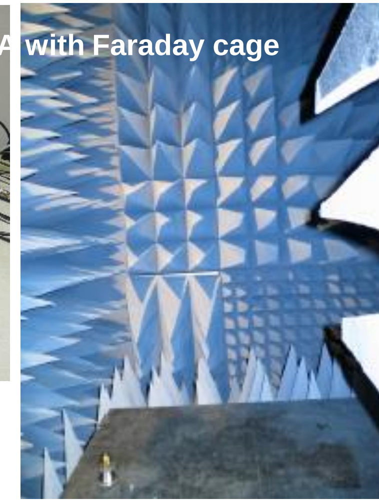
Representative results of a LA-ICP-MS analysis (non-destructive)



Choice of Readout: Testing Different Systems

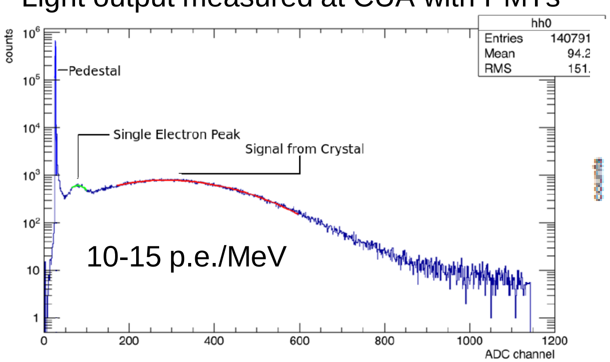




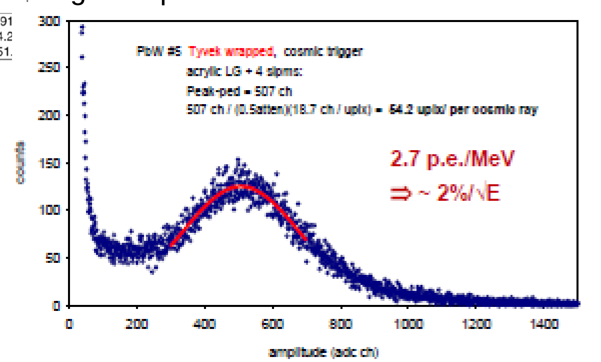


- ❑ For PMTs can cut at 1 p.e. – noise negligible
  - ➢ *Could be viable option – need to investigate contribution of magnetic fields at location of detector*
- ❑ For photodiodes need to demonstrate that can reach resolution and low noise level
- ❑ Tests different readout options with prototype – reconstruction, trigger thresholds, relative calibration, stability

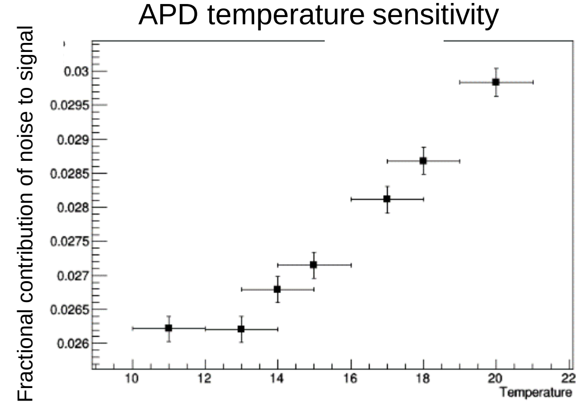
Light output measured at CUA with PMTs



Light output measured at BNL with 4 SiPMs



APD temperature sensitivity



Funding Request (FY18)

Crystal characterization for crystal specifications and impact on EIC detector performance

- Evaluate systematics between setups
- Characterize, including chemical analysis, 460 SICCAS crystals being produced in 2017 in collaboration with NPS project
- Evalute CRYTUR later growth cycle crystals

Prototype to establish limiting energy and position resolution, and, together with simulations, to evaluate options to reduce the constant term

- Construct prototype assuming suitable number of crystals is available
- Calibrate prototype with tagged photon beam at JLab
- Together with simulations evaluate uniformity of crystal response and statistical fluctuations of containment losses

Investigation of different readout systems and influence on resolution

- PMTs may be a viable option since not directly in magnetic field
- Evaluate photodiode readout options and long term stability

Budget Request FY2018

Item	FY18 ($)	FY19 ($)
Procure crystals from Crytur	**30k**	10k
Technical Support	**21k**	18k
Parts for prototype and construction	**38k**	
Travel	**28k**	28k
Parts for cooling system		38k
Parts for readout system	**31k**	32k
TOTAL	**148k**	126k

- **20% cut:** delay construction and testing of the prototype, continue crystal characterization studies but at lower efficiency and our general studies of different readout options . This limited continuation, even with a 20% cut, is enabled with the majority of our activities funded by the NPS project and internal funds.

- **40% cut:** Our focus would shift towards the NPS project, which would be the funding source for our activities, and we may only provide information relevant specifically for EIC. We would attempt to continue our general studies of different readout options at lower efficiency. These would proceed at significantly reduced efficiency regarding EIC. Construction and testing of the prototype is delayed.

Critical Issues and Path Forward

- Complete FY17 activities (that were not funded in FY17) that address calorimeter resolution performance like variations of crystal quality, choice of photosensors, and shower resonstruction

- Assuming FY18 activities completed successfully, R&D will focus on optimization of geometry, cooling, choices of readout

External Funding

- All of the FTEs required for working towards finalizing the crystal test setup and crystal characterization are provided by CUA/IPNO or external grants. The absence of any labor costs makes this proposed R&D effort extremely cost effective.
  - Nine people working on project – additional collaborators at JLab, Giessen University, Yerevan, VSL@CUA

- The 2014 and 2015 SIC crystals are provided through synergistic activities with independent research for the Neutral Particle Spectrometer (NPS) project at JLab.

- The expertise and use of specialized instruments required for crystal characterization and their chemical analysis, as well as additional crystals samples are made possible through collaboration with the Vitreous State Laboratory (VSL) at CUA that is also collaborating on the NPS project.

- Similarly, the work highly benefits from support groups within IPN Orsay and the expertise provided by Giessen University.

Publications and Talks

- C. Munoz-Camacho et al.. “R&D for high resolution calorimetry at the future Electron-Ion Collider”, Presentation at the XVIIth International Conference on Calorimetry in Particle Physics, 15-20 May 2016, Daegu, South Korea

- R. Trotta et al. “*Exclusive reactions and the PbWO4-based Inner Calorimeter for the Electron-Ion Collider*” presentation at the APS April 2017 meeting, Washington, DC

- T. Horn, C. Munoz-Camacho, C. Keppel, I. Strakovsky et al., arXiv:1704:00816 (2017) “*Workshop on High-Intensity Photon Sources (HIPS2017) Mini-Proceedings*”

- T. Horn et al., J.Phys. Conf. Ser. **587** (2015) 1, 012048 “*A PbWO4-based Neutral Particle Spectrometer in Hall C at 12 GeV JLab*”

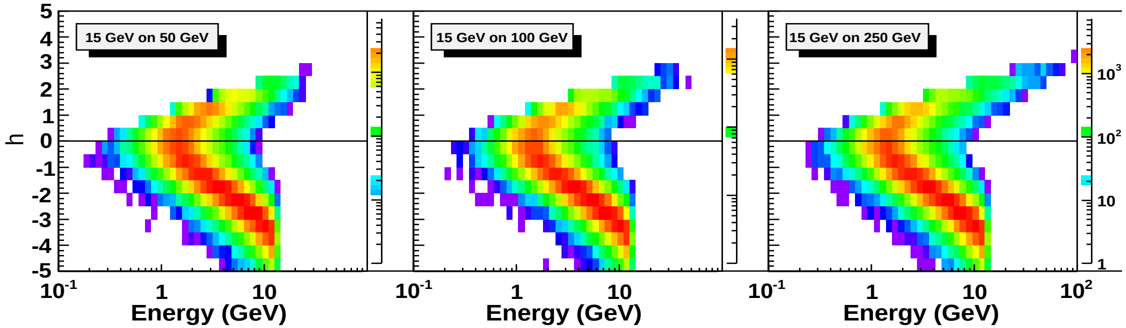
- T. Horn et al. “*Physics Opportunities with the Neutral Particle Spectrometer in Hall C*”, presentation at the APS DNP 2015 Fall meeting, Santa Fe, NM

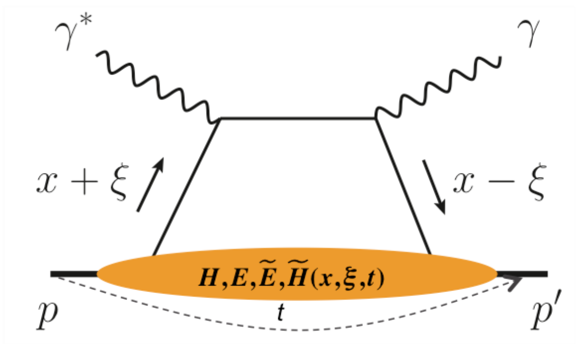
Example: Exclusive Reactions - DVCS

Slide from E. Aschenauer, EIC UG meeting Jan. 2016

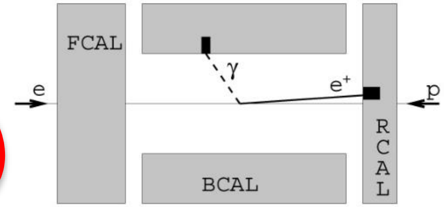
DVCS – photon kinematics:

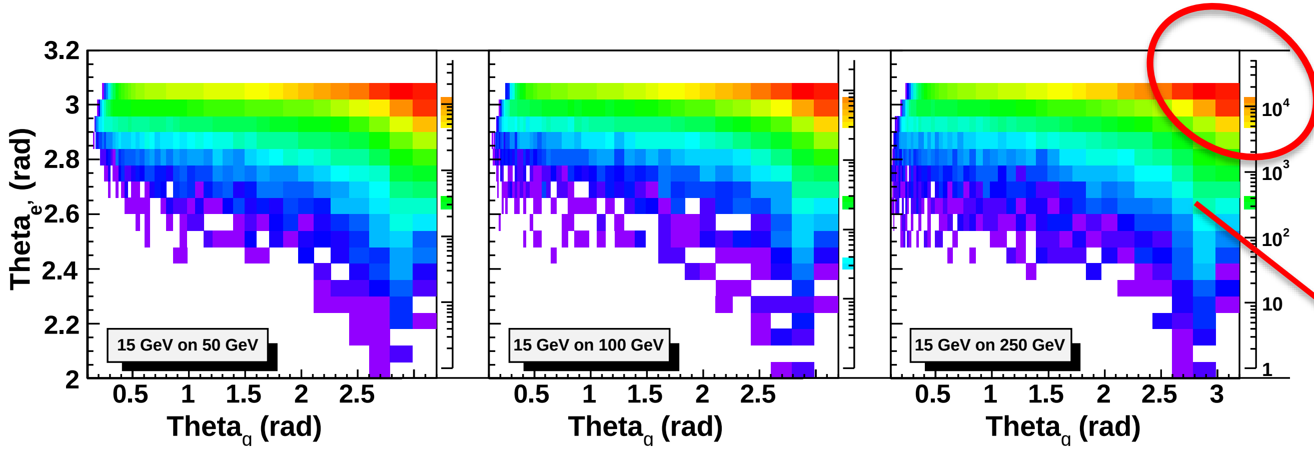
Cuts: $Q^2>1$ GeV, $0.01<y<0.85$

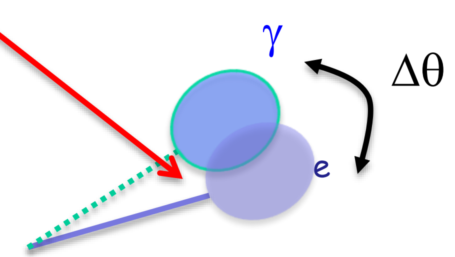




increasing Hadron Beam Energy influences max. photon energy at fixed η photons are boosted to negative rapidities (lepton direction)







ECal granularity: need to be able to distinguish clusters down to Δθ=1°